

DEUTERON COMPTON SCATTERING IN CHIRAL PERTURBATION THEORY

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Compton scattering on the deuteron is studied in the framework of baryon chiral perturbation theory to third order in small momenta, for photon energies of order the pion mass. The scattering amplitude is a sum of one- and two-nucleon mechanisms with no undetermined parameters. Our results are in good agreement with the intermediate energy experimental data, and a comparison is made with the recent higher-energy data obtained at SAL.

1 Introduction

At sufficiently low energy ω the spin-averaged forward Compton scattering amplitude for any nucleus is, in the nuclear rest frame:

$$T(\omega) = -\frac{1}{4\pi} \vec{\epsilon}' \cdot \vec{\epsilon} \left(\frac{Z^2 e^2}{AM} + (\alpha + \beta) \omega^2 + \dots \right), \quad (1)$$

where $\vec{\epsilon}$ and $\vec{\epsilon}'$ are the polarization vectors of the initial and final-state photons, Ze is the total charge of the nucleus, AM is its total mass, and α (*beta*) the electric (magnetic) polarizability.

Compton scattering on a deuteron target is an obvious candidate to measure the electromagnetic neutron polarizabilities. In this case, the cross section in the forward direction roughly goes as

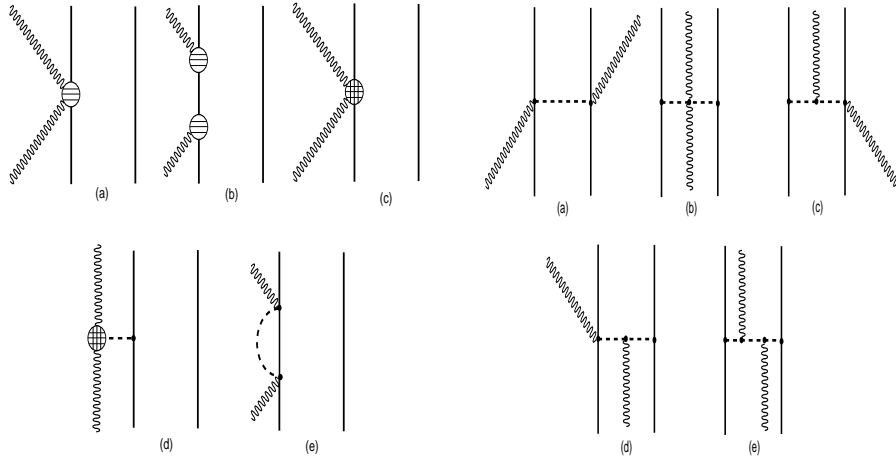


Figure 1: Characteristic one-body interactions which contribute to Compton scattering on the deuteron at order Q^2 (a) and at order Q^3 (b-e) (in the Coulomb gauge). The sliced blobs are vertex insertions from $\mathcal{L}^{(1)}$. The sliced and diced blobs are vertex insertions from $\mathcal{L}^{(2)}$.

Figure 2: Two-body interactions which contribute to Compton scattering on the deuteron at order Q^3 . Permutations are not shown.

$$\left. \frac{d\sigma}{d\Omega} \right|_{\theta=0} \sim (f_{Th} - (\alpha_p + \alpha_n)\omega^2)^2. \quad (2)$$

The sum $\alpha_p + \alpha_n$ may then be accessible via its interference with the dominant Thomson term for the proton, f_{Th} . Coherent scattering the deuteron has been measured at $E_\gamma = 49$ and 69 MeV by the Illinois group ¹. An experiment with tagged photons in the energy range $E_\gamma = 84.2 - 104.5$ MeV at Saskatoon has recently presented results ², while data for E_γ of about 60 MeV is being analyzed at Lund.

2 The χPT calculation

In this section, we outline how the various contributions are calculated following Ref.³. We can separate them into two classes: one-nucleon and two-nucleon mechanisms. One-nucleon diagrams are those which relate directly to contributions to Compton scattering on a single nucleon, while two-nucleon mechanisms contribute only in $A \geq 2$ nuclei.

Let us consider first the one-nucleon terms; a sample of the relevant diagrams is shown in Fig. 1. The only modification which must be made to the photon-nucleon amplitude for use in Compton scattering on the deuteron is that it must be boosted from the γN c.m. frame to the γNN c.m. frame.

In principle we cannot hope to extract neutron polarizabilities without a theory for the two-nucleon contributions, shown in Fig. 2. Comparison of diagrams in Figs. 1(e) and 2 shows that the same physics that produces dominant contributions to the polarizabilities generates the dominant two-nucleon contributions.

We calculate the cross section for Compton scattering on the deuteron including the single-scattering and two-nucleon mechanisms described above. The final result is insensitive to details of the deuteron wavefunction, and below we use the energy-independent Bonn OBEPQ wave function. The photon-deuteron T -matrix is then calculated and the laboratory differential cross section evaluated directly from it:

$$\frac{d\sigma}{d\Omega_L} = \frac{1}{16\pi^2} \left(\frac{E'_\gamma}{E_\gamma} \right)^2 \frac{1}{6} \sum_{M'\lambda'M\lambda} |T_{M'\lambda'M\lambda}^{\gamma d}|^2, \quad (3)$$

where E_γ and E'_γ are the initial and final photon energy in the laboratory frame respectively. Results are shown in Figs. 3,4,5. They represent the χPT predictions for Compton scattering on the deuteron ⁴.

3 Conclusion

We have calculated the differential cross section for Compton scattering on the deuteron in χPT up to $O(Q^3)$ ⁴. We have found:

- Reasonable agreement with the data at 49 MeV. At this energy $O(Q^3)$ corrections are not large compared to the leading $O(Q^2)$ result.
- Good agreement with the data at 69 MeV. At this energy the convergence appears to be good. This suggests that χPT at $O(Q^3)$ is providing reasonable neutron and two-nucleon contributions.
- A prediction at 95 MeV which is, however, plagued by considerable uncertainties. The cross section comes out somewhat smaller than at lower energies, in particular in the backward directions, although the full $O(Q^4)$ amplitude is likely to be somewhat bigger at back angles. It seems that a more stringent test of χPT at these energies will have to wait for a next-order calculation.

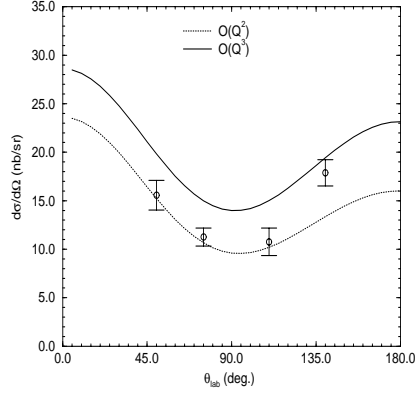


Figure 3: Results of the $O(Q^2)$ (dotted line) and $O(Q^3)$ (solid line) calculations at a photon laboratory energy of 49 MeV. The data points of Ref. ¹ are also shown.

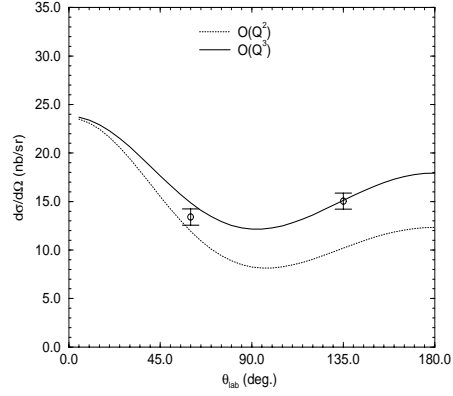


Figure 4: Results of the $O(Q^2)$ (dotted line) and $O(Q^3)$ (solid line) calculations at a photon laboratory energy of 69 MeV. The data points of Ref. ¹ are also shown.

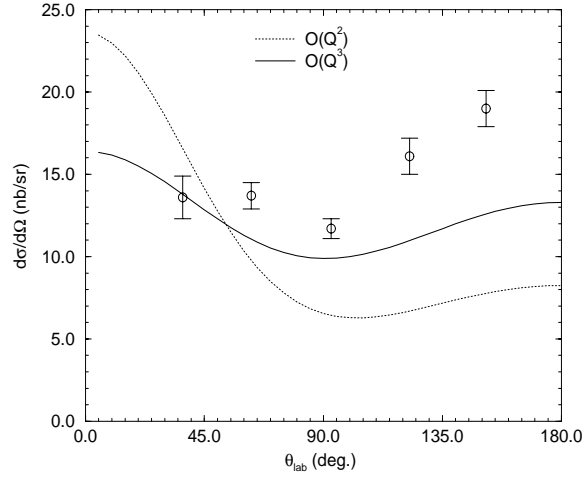


Figure 5: Results of the $O(Q^2)$ (dotted line) and $O(Q^3)$ (solid line) calculations at a photon laboratory energy of 95 MeV. The recent SAL data points of Ref. ² are also shown.

References

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